



UNITED
NATIONS



Framework Convention
on Climate Change

Distr.
GENERAL

FCCC/TP/2003/3
14 November 2003

ENGLISH ONLY

COMPILATION OF DATA ON EMISSIONS FROM INTERNATIONAL AVIATION

Technical paper

Summary

The results of a comparison between preliminary data from the AERO model and the latest available inventory information from Annex I Parties in relation to fuel consumption and CO₂ emissions data for domestic and international aviation are presented and discussed. Although the comparison shows relatively good agreement in total fuel consumption and CO₂ emissions across all Parties considered, there are large differences between UNFCCC and AERO data for a number of Annex I Parties. An update on the work being undertaken by the International Civil Aviation Organization (ICAO) and brief descriptions of two new models (AERO2K and SAGE) that are currently under development by ICAO are also provided. Initial results from these two new models are expected in spring 2004.

UNITED NATIONS
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FEB 02 2004

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I. INTRODUCTION

A. Mandate

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its eighteenth session, endorsed the elements for future methodological work outlined in paragraph 64 of document FCCC/SBSTA/2003/INF.3,¹ which contained a request to the International Civil Aviation Organization (ICAO) to provide modelled fuel consumption and emissions data arising from the use of validated aviation models for at least 2000 and 2001, before SBSTA 19. This would include data by country, airline and aircraft/engine combinations.

B. Scope of the paper

2. Because of the on-going development of two new aviation models (AERO2K and SAGE) and the complexity of the calculation of emissions from aviation, it was not possible for ICAO to provide the information mentioned in paragraph 1 above before SBSTA 19. Initial results from the two models are expected in spring 2004. Following their release, these results will be subject to analysis and validation by the ICAO Committee on Aviation Environmental Protection (CAEP).² ICAO has provided information on the status and structure of the two models, and a summary of this information is compiled in this paper.

3. Preliminary information from an existing model (AERO) on fuel consumption and CO₂ emissions for the years 1992 and 1999 were made available during an expert meeting organized by ICAO in February 2003. For the expert meeting, the AERO data were originally compared with data submitted by Parties included in Annex I to the Convention (Annex I Parties) in 2002. This paper presents the results of the comparison (undertaken by the secretariat) between AERO data and the latest available inventory information, including data submitted by Annex I Parties after February 2003.

4. Since the AERO model was endorsed by ICAO for application for other analytical purposes, the AERO data presented in this paper have not been considered by the CAEP for the purpose of providing specific data on fuel consumption and emissions by country. Therefore the AERO data cannot be regarded as official data from ICAO. They are used here solely as an example of the information by country that this particular model could provide. No conclusions should be derived from the comparison of the results at this stage.

II. COMPARISON BETWEEN UNFCCC DATA AND DATA FROM THE AERO MODEL

A. Background

5. In February 2003 an expert meeting was held in Montreal, Canada, to discuss methodological issues relating to emissions from international aviation.³ In preparation for the meeting UNFCCC data were compared with data on fuel consumption and emissions from the AERO model⁴ for the purpose of

¹ FCCC/SBSTA/2003/10, paragraph 29 (b).

² The ICAO data will also be considered during an expert meeting (tentatively scheduled for spring 2004) to be organized by ICAO in accordance with the invitation of the SBSTA (FCCC/SBSTA/2003/10, para. 29 (c)).

³ FCCC/SBSTA/2003/INF.3.

⁴ A description of the AERO model can be found in *Comparison of UNFCCC Data on Emissions from Domestic and International Aviation with Data from the AERO Model*, SMI-WP/3, ICAO, February 2003, which can be obtained directly from the ICAO secretariat (attention: Secretary of CAEP). More detailed information is published in *Aviation Emissions and Evaluation of Reduction Options/AERO* published by the Directorate General for Civil Aviation, Ministry of Transport, Public Works and Water Management of the Kingdom of the Netherlands, July 2002, ISBN 90-369-1792-1.

highlighting discrepancies between the two data sets. The AERO model was developed by the Dutch Civil Aviation Authority in the period 1994–2000, and is an internationally accepted tool for the computation of emission reduction options. It was designed to evaluate fiscal, regulatory, operational and technical measures to reduce air traffic impacts on the atmosphere and has been applied in a number of international studies.

6. The base year in the AERO model is 1992. AERO computational results with respect to aviation emission levels for 1992, as presented in this paper, are based on the Unified Database.⁵ Computational results for the year 1999, as also presented in this paper, are based on a “scenario computation” for the period 1992–1999 for which the growth in aviation demand was computed from observed growth in gross national product, population and exports (for cargo demand) in that period, with the results being verified with actual data for the years 1997 and 1998.

7. The territories of countries in the AERO model are based on the geopolitical situation in 1992 and, hence, fuel consumption and emission data cannot be assessed for some Annex I Parties, in particular the countries in the former Soviet Union (e.g. Estonia, Latvia, Lithuania), the countries in the former Yugoslavia and the Czech Republic and Slovakia.⁶ The AERO numbers for the Czech Republic in all tables presented in the next two sections relate to both the Czech Republic and Slovakia.

8. The AERO model computes fuel consumption for aviation and emissions of CO₂, SO₂, H₂O, C_xH_y, CO and NO_x. The results of the comparison between the AERO model data for the years 1992 and 1999 and the latest available UNFCCC data are presented in this paper only for fuel consumption and CO₂ emissions for domestic and international aviation.

B. Comparison of fuel consumption data

9. Fuel consumption data, as computed by the AERO model for the expert meeting, are presented in tables 1 and 2 for 1992 and 1999, respectively. Fuel consumption is split into domestic and international traffic components and is presented by Annex I Party. All fuel consumption on international flights departing from a particular country is allocated to that country, whereas domestic fuel consumptions relate to all flights within a country. The AERO model computes fuel consumption in mass units (Gg) but Annex I Parties report fuel consumption in energy units (TJ). To facilitate the comparison between the two data sets, the AERO data were converted from Gg to TJ using default conversion factors from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (1996 IPCC Guidelines).⁷

10. For reference, total fuel consumption from the International Energy Agency (IEA) are also presented in tables 1 and 2. The IEA totals refer to the sum of aviation gasoline, gasoline type jet fuel and kerosene type jet fuel for both domestic and international aviation. The IEA data were converted from mass units to TJ using default conversion factors from the 1996 IPCC Guidelines.⁸

⁵ The Unified Database merges the content of four major aviation databases: the ICAO 1992 “Traffic by Flight Stage” (TFS) data for international scheduled movements; the US Department of Transport 1992 “T-100” data for United States domestic scheduled flights; the July 1992 ABC (now OAG) timetable for scheduled movements; and the ANCAT (Abatement of Nuisances Caused by Air Transport) database for April 1992.

⁶ In the AERO model, it is possible to change the mapping of cities to these newly formed countries. However, this involves a considerable amount of work and for the purpose of this comparison this mapping was not done.

⁷ The conversion factor used was the default calorific value for jet kerosene. For Parties using net calorific value the factor is 44.59 TJ/Gg (see volume II of the 1996 IPCC Guidelines, page 1.6, table 1.3); for Parties using gross calorific value the factor is assumed to be 5 per cent higher at 46.82 TJ/Gg.

⁸ For Parties using net calorific value, conversion factors were 44.80 TJ/Gg for aviation gasoline and gasoline type jet fuel and 44.59 TJ/Gg for kerosene type jet fuel (see volume II of the 1996 IPCC Guidelines, page 1.6, table 1.3). For Parties using gross calorific value the conversion factors were assumed to be 5 per cent higher.

11. Differences in total fuel consumption per country (sum of domestic and international fuel consumption) between UNFCCC and AERO data have been calculated only for those Parties for which both UNFCCC and AERO data are available.

Table 1. Comparison of fuel consumption data (TJ) for 1992

Party	Domestic		International		Total		Difference as % of UNFCCC value	IEA data
	UNFCCC	AERO	UNFCCC	AERO	UNFCCC	AERO		
Australia	56 129	81 982	69 500	118 548	125 629	200 530	59.6	131 717
Austria	1 027	713	14 913	14 670	15 940	15 384	-3.5	16 320
Belgium		45		33 220		33 264		40 488
Bulgaria		223		3 746		3 969		13 734
Canada	134 468	94 202	38 305	93 125	172 773	187 327	8.4	178 036
Czech Republic		1 338		11 683		13 020		7 716
Denmark	2 664	1 561	23 539	25 372	26 203	26 932	2.8	27 780
Finland	5 442	7 982	11 452	22 027	16 894	30 009	77.6	17 435
France	62 835	18 772	137 318	145 230	200 154	164 002	-18.1	185 855
Germany	41 217	26 219	164 867	199 763	206 084	225 982	9.7	230 812
Greece	21 537	5 039	31 168	26 576	52 705	31 614	-40.0	52 711
Hungary		0		4 236		4 236		5 930
Iceland		0		3 656		3 656		3 255
Ireland	807	1 338	17 405	13 422	18 213	14 759	-19.0	13 422
Italy		22 830		67 866		90 696		103 405
Japan	123 505	102 691	201 068	258 845	324 573	361 536	11.4	339 149
Luxembourg		0		7 001		7 001		5 797
Netherlands	2 697	490	81 000	76 293	83 697	76 784	-8.3	85 613
New Zealand		10 956	19 450	37 503	19 450	48 459	149.1	29 688
Norway		15 071		7 892		22 964		22 295
Poland		312		4 191		4 504		10 256
Portugal	12 659	3 835	13 003	18 460	25 662	22 295	-13.1	26 888
Spain	50 168	32 462	66 861	95 155	117 029	127 617	9.0	120 372
Sweden	8 704	12 574	12 308	25 327	21 012	37 902	80.4	35 839
Switzerland		4 816		51 903		56 718		50 922
United Kingdom	30 949	24 792	224 650	239 047	255 600	263 839	3.2	298 443
United States	2 504 850	1 636 219	705 037	664 563	3 209 886	2 300 782	-28.3	3 213 681
Comparable totals^a	3 059 659	2 061 825	1 831 844	2 073 926	4 891 503	4 135 752	-15.5	
Subtotal	3 059 659	2 106 460	1 831 844	2 269 320	4 891 503	4 375 780		
All other Parties		455 665		1 280 982		1 736 647		
Total		2 562 125		3 550 302		6 112 427		

^a Total fuel consumption for the Parties for which both the UNFCCC and AERO have data.

Table 2. Comparison of fuel consumption data (TJ) for 1999

Party	Domestic		International		Total			Difference as % of UNFCCC value	IEA data
	UNFCCC	AERO	UNFCCC	AERO	UNFCCC	AERO			
Australia	59 625	109 933	105 330	172 813	164 955	282 746	71.4	182 657	
Austria	1 660	981	21 246	18 772	22 906	19 753	-13.8	23 544	
Belgium		89		39 016		39 105		67 464	
Bulgaria	503	223	4 522	4 504	5 024	4 727	-5.9	5 351	
Canada	193 062	118 127	44 471	119 110	237 533	237 237	-0.1	238 338	
Czech Republic	187	1 516	7 610	12 084	7 797	13 600		7 982	
Denmark	2 410	2 140	31 812	37 768	34 222	39 908	16.6	36 564	
Finland	6 561	9 631	14 946	28 627	21 507	38 258	77.9	22 162	
France	84 548	23 053	192 219	187 144	276 768	210 197	-24.1	281 142	
Germany	56 271	29 652	225 083	284 752	281 354	314 404	11.7	304 417	
Greece	23 722	5 797	32 016	33 933	55 738	39 730	-28.7	55 738	
Hungary		0	8 424	4 727	8 424	4 727	-43.9	9 097	
Iceland	448	0	5 134	4 727	5 582	4 727	-15.3	5 574	
Ireland	1 183	1 694	21 593	16 498	22 776	18 193	-20.1	23 008	
Italy	33 883	26 531	105 581	87 842	139 464	114 373	-18.0	154 727	
Japan	156 870	159 543	260 027	366 084	416 897	525 627	26.1	424 137	
Luxembourg		0		8 205		8 205		14 402	
Netherlands	5 747	669	137 949	102 780	143 696	103 449	-28.0	147 324	
New Zealand	11 124	13 063	28 806	52 766	39 930	65 829	64.9	41 391	
Norway	15 805	18 326	12 884	9 988	28 689	28 315	-1.3	32 773	
Poland		401		6 198		6 599		15 964	
Portugal	18 675	4 414	12 304	22 250	30 979	26 665	-13.9	32 283	
Spain	71 154	39 105	106 492	120 036	177 646	159 142	-10.4	182 708	
Sweden	9 563	14 269	25 710	32 417	35 273	46 686	32.4	40 979	
Switzerland	3 483	6 287	61 748	71 701	65 231	77 988	19.6	67 643	
United Kingdom	38 394	30 812	369 184	319 532	407 578	350 344	-14.0	443 584	
United States	2 809 136	1 992 566	884 568	836 627	3 693 704	2 829 192	-23.4	3 696 759	
Comparable totals^a	3 604 012	2 608 334	2 719 660	2 947 481	6 323 672	5 555 814	-12.1		
Subtotal	3 604 012	2 608 824	2 719 660	3 000 900	6 323 672	5 609 724			
All other Parties		608 921		1 931 192		2 540 114			
Total		3 217 745		4 932 092		8 149 838			

^a Total fuel consumption for the countries for which both the UNFCCC and AERO have data.

12. With respect to tables 1 and 2 the following observations can be made:

- (a) For Hungary, Iceland and Luxembourg AERO does not compute any domestic fuel consumption. This implies that there are no major flight stages in these countries which are taken into account in the AERO model. Possible minor domestic flight stages in these countries might have been aggregated into one flight stage representing a group of minor flight stages;
- (b) According to the AERO computation for 1999 about 80 per cent of the global domestic aviation fuel consumption took place in the Annex I Parties listed in table 2 (i.e. 2,608,824 PJ as a percentage of 3,217,745 PJ). About 60 per cent of the global international aviation fuel consumption in 1999 took place on flight stages departing from the Annex I Parties listed in table 2 (i.e. 3,000,900 PJ as a percentage of 4,932,092 PJ). For 1992 these percentages are somewhat higher, indicating that in the period 1992–1999 aviation traffic within and from other Parties was growing faster compared to that within and from the Annex I Parties listed in tables 1 and 2;
- (c) For both 1992 and 1999 the AERO results for international fuel consumption (across all countries) are higher compared to the UNFCCC data, whereas for domestic fuel consumption (across all countries) they are lower compared to the UNFCCC data. Despite the relatively small differences for the comparable totals (–15.5 per cent for 1992 and –12.1 per cent for 1999), the differences between UNFCCC and AERO total fuel consumption for individual countries vary between –44 and +78 per cent;
- (d) For some countries (for example, Australia, Finland and New Zealand) the differences are rather large, with the AERO model computing the fuel consumption (both domestic and international) at a much higher level compared to the data reported to the UNFCCC;
- (e) For most Parties the UNFCCC and AERO data are generally consistent for the two years considered. For a few countries, however, the percentage differences are high; for Finland, for example, the AERO numbers are about 78 per cent higher than the UNFCCC ones, for both 1992 and 1999;
- (f) The growth in aviation fuel consumption in the period 1992–1999 is comparable between UNFCCC and AERO. For those countries which reported domestic and international fuel consumption to the UNFCCC for both 1992 and 1999, the growth in fuel consumption over the period is 28 per cent. For the same set of countries the growth in fuel consumption according to AERO is 24 per cent.

C. Comparison of CO₂ emission data

13. Emissions of CO₂ based on both UNFCCC reported data and AERO modeled data are presented in tables 3 and 4 for 1992 and 1999, respectively. An implied emission factor (IEF) per country is presented in terms of t CO₂/TJ is also shown. Comparing IEFs can show whether differences in emission factors are responsible for differences between UNFCCC and AERO emissions data. Where CO₂ emissions between UNFCCC and AERO are different, but IEFs are comparable, the difference in emission data is due to a difference in fuel consumption.

Table 3. Comparison of CO₂ emissions (Gg) for 1992

Party	Domestic		International		Total		Implied emission factor (t CO ₂ /TJ)		
	UNFCCC	AERO	UNFCCC	AERO	UNFCCC	AERO	% of UNFCCC value	UNFCCC	AERO
Australia	3 880	5 527	4 796	7 993	8 676	13 519	56	69.1	67.4
Austria	75	51	1 077	1 039	1 152	1 090	-5	72.3	70.9
Belgium	8	4	2 584	2 353	2 592	2 357	-9	70.9	-2.0
Bulgaria		15		266		281			70.8
Canada	9 426	6 351	2 686	6 279	12 112	12 630	4	70.1	67.4
Czech Republic	95			828		923			-2.4
Denmark	192	110	1 695	1 797	1 887	1 907	1	72.0	70.8
Finland	386	565	811	1 560	1 197	2 125	78	70.8	-1.7
France	4 498	1 330	9 831	10 283	14 329	11 613	-19	71.6	70.8
Germany	3 050	1 857	12 200	14 142	15 250	15 999	5	74.0	70.8
Greece	1 524	355	1 460	1 883	2 984	2 238	-25	56.6	70.8
Hungary	0			300		300			70.8
Iceland		0		260		260			71.1
Ireland	58	95	1 243	950	1 300	1 045	-20	71.4	70.8
Italy		1 618		4 805		6 423			-0.8
Japan	8 292	7 269	14 210	18 326	22 502	25 595	14	69.3	70.8
Luxembourg		0		495		495			2.1
Netherlands	197	35	5 910	5 402	6 107	5 438	-11	73.0	70.7
New Zealand	639	739	1 323	2 529	1 961	3 269	67		-3.0
Norway		1 069		560		1 628			70.8
Poland		23		295		319			-0.3
Portugal	893	271	917	1 306	1 810	1 577	-13	70.5	70.7
Spain	3 654	2 298	4 854	6 737	8 508	9 035	6	72.7	70.8
Sweden	636	890	900	1 793	1 536	2 684	75	73.1	-2.6
Switzerland		340		3 674		4 015			-3.2
United Kingdom	2 220	1 755	16 122	16 925	18 341	18 680	2	71.8	70.9
United States	167 015	110 328	47 031	44 810	214 046	155 137	-28	66.7	67.4
Comparable totals^a	206 643	139 830	129 648	146 134	336 291	285 964	-15		
Totals	206 643	142 990	129 648	157 591	336 291	300 580			
All other Parties	32 260				90 693	122 953			

^a Total emissions for the countries for which both the UNFCCC and AERO have data.

Table 4. Comparison of CO₂ emissions (Gg) for 1999

Party	Domestic		International		Total		Implied emission factor (t CO ₂ /TJ)	
	UNFCCC	AERO	UNFCCC	AERO	UNFCCC	AERO	UNFCCC	AERO
Australia	4 691	7 412	7 268	11 654	11 959	19 066	59	72.5
Austria	121	68	1 542	1 330	1 662	1 398	-16	72.6
Belgium		5	4 381	2 762	4 381	2 767	-37	70.8
Bulgaria	35	16	319	318	355	334	-6	70.6
Canada	13 168	7 965	3 032	8 031	16 200	15 997	-1	68.2
Czech Republic		107	539	857	539	964	79	69.1
Denmark	174	152	2 290	2 674	2 464	2 826	15	72.0
Finland	465	681	1 058	2 026	1 523	2 706	78	70.8
France	6 053	1 631	13 761	13 250	19 814	14 881	-25	71.6
Germany	4 164	2 099	16 656	20 159	20 820	22 258	7	74.0
Greece	1 679	409	2 881	2 402	4 560	2 811	-38	81.8
Hungary	0	596	334	596	334	334	-44	70.8
Iceland	32	0	363	335	395	335	-15	70.8
Ireland	84	119	1 542	1 168	1 626	1 287	-21	71.4
Italy	2 397	1 877	7 468	6 219	9 865	8 096	-18	70.7
Japan	10 532	11 297	18 377	25 918	28 909	37 215	29	69.3
Luxembourg		0	1 019	580	1 019	580	-43	
Netherlands	420	47	10 070	7 276	10 490	7 323	-30	73.0
New Zealand	757	880	1 959	3 556	2 716	4 437	63	68.0
Norway	1 155	1 297	942	706	2 097	2 003	-4	73.1
Poland		29	346	438	346	467	35	
Portugal	1 317	312	868	1 577	2 185	1 888	-14	70.5
Spain	5 188	2 769	7 737	8 498	12 924	11 267	-13	72.8
Sweden	699	1 009	1 879	2 295	2 578	3 305	28	73.1
Switzerland	255	444	4 520	5 076	4 775	5 520	16	73.2
United Kingdom	2 753	2 181	26 494	22 624	29 247	24 806	-15	71.8
United States	186 771	134 357	58 833	56 412	245 604	190 768	-22	66.5
Comparable totals ^a	242 908	177 022	196 740	208 476	439 648	385 496	-12.3	
Totals	242 908	177 164	196 740	208 476	439 648	385 640		
All other Parties		43 113		136 729	179 842			

^a Total emissions for the countries for which both the UNFCCC and AERO have data.

D. Additional remarks

14. The AERO model offers the potential to provide fuel consumption and emissions data by country as requested by the SBSTA, subject to further improvements of the model input parameters and data. In relation to data by airlines and aircraft/engine combinations the following remarks can be made:

(a) The AERO model calculations are based on the Unified Database, which holds data on civil aircraft movements and air passenger and cargo demand for the base year 1992 covering flights between over 50,000 city pairs. After a grouping of minor city pairs, this results in some 19,000 city-to-city flight stages being explicitly distinguished in the AERO model. The Unified Database also holds information on the operators of the flights;

(b) In the AERO model, aircraft flights are specified by 10 generic aircraft types (based on relevant combinations of range and capacity) and two technology levels, 'older' and 'current', which are defined by certification age. The older fleet consists of all aircraft with a certification age of 12 years or more prior to the review year (baseline or scenario year). Different fuel use characteristics are computed for the 10 generic aircraft types based on the weighted average fuel use characteristics of all aircraft belonging to a particular aircraft type.

15. The information above suggests that it is probably possible for the AERO model to provide the additional data requested by the SBSTA. However, extracting this information in a usable form would require additional effort and resources. Other models, currently being evaluated, could possibly provide more accurate information to supplement data collection and analysis for national inventories of greenhouse gases, particularly for CO₂ and NO_x emissions.

III. BRIEF DESCRIPTIONS OF THE AERO2K AND SAGE MODELS

16. The SBSTA has noted the need for ICAO modelled data by country, airline and aircraft/engine combinations.⁹ As mentioned above, ICAO expects to receive data generated by the AERO2K and SAGE models in spring 2004. Both models will be important in providing data to the secretariat and although their capabilities differ, the model developers have agreed to share data to ensure the consistency of the results. The following sections provide information on these two tools.

A. AERO2K

1. Introduction

17. The AERO2K project is supported through the European Commission Fifth Framework programme and is under development by a consortium led by QinetiQ (United Kingdom) with DLR (Germany), NLR (Netherlands), Eurocontrol, Airbus (France), Manchester Metropolitan University (United Kingdom) and the Department of Trade and Industry (United Kingdom).

2. Objectives

18. The objective of AERO2K is to develop a new four dimensional (4-D: latitude, longitude, height and time) gridded database of global aircraft emissions of priority pollutants and to improve methodologies and analytical tools that facilitate novel and improved evaluations of the impact of aircraft emissions on the global atmosphere. Within this overall objective, the current AERO2K project will provide improved routing assumptions for present day traffic (e.g. using radar data); improved methodologies for establishing flight profiles and fuel usage for engine/aircraft combinations; new inventory parameters e.g. distances flown per grid cell per hour, needed for contrail impact analysis; and a new 25-year forecast of aviation emissions which encompasses the parameters identified above.

⁹ FCCC/SBSTA/2003/INF.3, paragraph 64.

3. Design

19. The inventory software package includes an MS Access database which stores data on aircraft flight movements over a specified period and geographical area. The emissions can be displayed in a 4-D grid. Grid sizes are flexible to suit the application and the emissions are calculated from knowledge of flight routing, flight phase, aircraft and engine type, thrust settings, fuel consumption and emissions factors. Although this approach is not in itself novel, the techniques used in generating the input information will provide a substantially more reliable data set than has previously been available. Such techniques include use of actual radar tracking data (as opposed to great circle data); increased number of representative aircraft types; calculation of aircraft in-flight weight changes with consequent variations in fuel burn and emissions; characterization of landing and take-off (LTO) times by airport; and use of latest available information and methodology for calculation of LTO and altitude emissions.

4. Outputs

20. The main outputs of the current project will be a new civil air traffic movements database for 2002 based upon improved routing assumptions and methodologies; emissions inventories for pollutants (CO₂, H₂O, CO, SO₂, NO_x, soot (mass) and hydrocarbons) from aircraft; uncertainty analyses; an inventory of distances flown in and between regions of the world; and a new 2025 emissions forecast. In addition, emissions inventory software tools are expected to be created and integrated into the software package, which will then be capable of developing and analysing a range of allocation scenarios for aviation emissions.

5. Validation

21. Currently (October 2003), the inputs to the inventory software package have been specified and initial testing of the integrated software has been carried out. Results in terms of the 2002 inventory and the 2025 forecast are expected in spring 2004. Further work under consideration includes wider validation and comparison of the model output with other models and data; integration of additional modules to provide information, for example, on atmospheric and climate impacts; addition of further pollutants (e.g. particulates) as information becomes available; and additional runs of the model.

B. SAGE model

1. Introduction

22. The United States Federal Aviation Administration Office of Environment and Energy has developed the System for assessing Aviation's Global Emissions (SAGE), with support from the Volpe National Transportation Systems Center, the Massachusetts Institute of Technology and the Logistics Management Institute.

2. Objective

23. The objective is for SAGE to be an internationally accepted computer model that is based on the best available data and methodologies, and used for estimating aircraft emissions (CO₂, CO, HC, NO_x, H₂O, and SO_x modelled as SO₂) over the whole flight regime including the landing and take-off cycle, and cruise. With regard to scope, the model is capable of analyses on an aircraft, airport, regional, and global level. Various operational, policy and technology-related scenarios can be evaluated using this model to assess their potential effects on global aircraft emissions.

3. Model structure

24. SAGE comprises four basic computational modules: aircraft movements; capacity and delay; fuel burn and emissions; and forecasting. These modules encompass both the methods and the input data requirements to run the model. SAGE was developed using the best available data and methods that



allow high-resolution and high-fidelity modelling of aircraft fuel burn and emissions during all phases of flight. Similar to AERO2K, the emissions can be displayed in a 4D grid (latitude, longitude, height and time). Grid sizes are flexible to suit the application and the emissions are calculated from knowledge of flight routing, flight phase, aircraft and engine type, thrust settings, fuel consumption and emissions factors.

4. Outputs

25. The model has generated an inventory of aircraft fuel burn and emissions for the years 2000 to 2002, based upon detailed knowledge of worldwide aircraft movements. These inventories and those for subsequent years will help to determine trends in aircraft emissions on a regional and global level, allow for more accurate comparisons to emissions from other industries, and provide a basis for forecasts of future aircraft greenhouse gas emissions. Detailed knowledge of aircraft movements allows for analysis of fuel burn and emissions within regions and between regions using SAGE.

5. Validation

26. Preliminary validation work has shown good agreement on both modular and system levels. It is expected that additional validation work will be conducted to determine areas for model improvement and to better understand areas of uncertainty. Model improvements that incorporate higher-resolution inputs will allow for SAGE to provide higher-fidelity results. Emission reduction options relating to new emissions reduction technologies and new operational procedures and strategies could be analysed with SAGE once the appropriate input data are made available.

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